

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



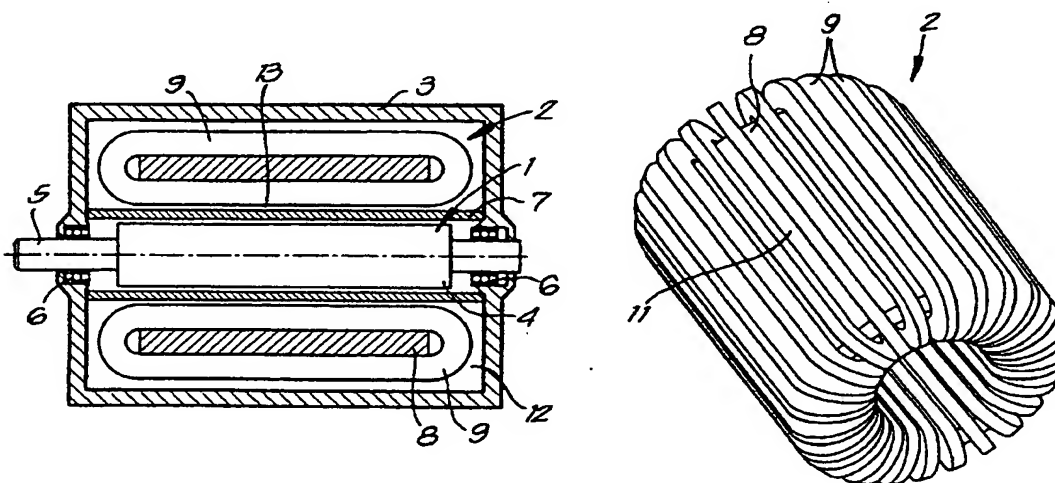
(43) International Publication Date
17 May 2001 (17.05.2001)

PCT

(10) International Publication Number
WO 01/35513 A1

- (51) International Patent Classification⁷: H02K 3/04, 9/19, 9/19
- (74) Agent: **DONNE**, Eddy; Bureau M.F.J. Bockstael N.V., Arenbergstraat 13, B-2000 Antwerpen (BE).
- (21) International Application Number: PCT/BE00/00136
- (22) International Filing Date:
9 November 2000 (09.11.2000)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
99870233.6 9 November 1999 (09.11.1999) EP
- (71) Applicant (for all designated States except US): **ATLAS COPCO AIRPOWER**, NAAMLOZE VENNOOTSCHAP [BE/BE]; Boomsesteenweg 957, B-2610 Wilrijk (BE).
- (72) Inventor; and
- (75) Inventor/Applicant (for US only): **NILSON**, Thord, Agne, Gustaf [SE/SE]; Långsjövägen 2B, S-135 54 Tyreso (SE).
- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
- Published:
— With international search report.
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: ELECTRICAL MACHINE COMPRISING A STATOR WITH WINDINGS



(57) Abstract: The invention relates to an electrical machine, for example a motor or a generator, comprising a housing (3) and therein a stator (2) comprising a tubular core (8) and windings (9) surrounding the core wall, said stator windings (9) extending axially and radially with respect to the axis of the core (8), the machine comprising means for cooling the windings (9). As well on the inside as on the outside of the core (8) the windings (9) are for at least 95 % spaced apart, forming gaps (11) between them, the cooling means comprising a cooling medium in these gaps (11).

WO 01/35513 A1

Electrical machine comprising a stator with windings.

5 The invention relates to an electrical machine, for
example a motor or a generator, comprising a housing and
therein a stator comprising a tubular core and windings
surrounding the core wall, said stator windings extending
axially and radially with respect to the axis of the core,
10 whereby the machine comprises means for cooling the
windings.

The continuous output power of such machine is primarily
limited by the cooling of the stator windings.

15 These stator windings are normally composed of a
relatively thick bundle of conductors and the number of
adjacent conductors increases towards the core as well
from the outer side as from the inner side of the core.

20 At the inner side of the core, adjacent windings
practically touch each other and the space between the
rotor and the stator core is practically completely filled
with windings except for a small ring-shaped air gap
25 between the windings and the rotor.

This means that the portion of the windings situated at
the inside the stator core can only be cooled towards the
core and said air-gap.

30 Because of the limited heat conduction in the core and
additional losses in the core, it is normally only
possible to evacuate a limited part of the heat via the

core.

Most of the heat should be evacuated via the air gap, but it will be difficult to cool in this way the centre
5 portion of the winding parts at the inside of the core.

The cooling of these windings is therefore limited.

To improve the cooling, it is known to add cooling means.
10

An electrical machine of the above kind with cooling means is disclosed in US-A-5.304.883. The stator windings comprise two portions, a first inner portion being located within the air gap between the core wall and the rotor and
15 a second outer portion being situated outside this gap.

The windings of the outer second portions have a greater cross-section area and thus a greater thermal mass than the windings of the first inner portions, providing a heat
20 sink for the first portions and permitting the first portions to be cooled more efficiently.

The stator includes an elongated bore seal sealing the house to define an annular stator chamber and the housing
25 provides inlet and outlet ports that are in fluid communication with the chamber allowing a coolant to flow in and out said chamber for cooling the windings.

Windings having two portions are of a more complicated
30 construction. Moreover the cooling is still limited as adjacent windings still practically touch each other so that the space between the rotor and the stator core is practically completely filled with the exception of a

small space at the outer side of the core as the outer portions radially extend a little farther than the inner portions.

- 5 The invention seeks to provide an electrical machine having an improved cooling of the stator windings.

In accordance with the invention, this object is accomplished by the fact that as well on the inside as on
10 the outside of the core the windings are for at least 95%, and preferably completely, spaced apart, forming gaps between them, the cooling means comprising a cooling medium in these gaps.

- 15 This means that, also on the inside of the core, the sides of the windings form cooling areas for evacuating heat by means of the cooling medium. Not only the cooling area is increased but the distance to the centre portion of the winding parts at the inner side of the core and a cooling
20 area is relatively small.

Moreover also parts of the inner side of the tubular stator core are cooled so that the cooling of the core is also improved and thereby also the possibility to cool the
25 windings through the core is increased.

A stator with angularly spaced windings is disclosed as prior art in US-A-4.103.197, but the windings are not cooled.

30

Preferably, the windings have the shape of thin discs.

The smaller the discs the greater the greater the possible

number of discs and the greater the number of disks, the greater the cooling.

Preferably the windings meant herebefore are segments of
5 the windings normally provided for each pole relating to one phase.

The classical windings corresponding to each pole is split
up in a number of smaller windings electrically connected
10 to each other.

The greater the total number of windings, the greater the number of gaps between them and the greater the possibly cooling.

15 The windings may comprise a wire consisting of individually insulated conductors, these conductors being wires or strands. This kind of wire is commonly known as Litz wire.

20 Preferably then the conductors of the winding wire extend in a zigzag pattern between the edges of the winding, said edges being in thermal conductive contact with said cooling medium.

25 In a section perpendicular to the winding, and in the transversal direction there is only one wire with in zigzag extending insulated conductors. In known windings, the conductors of the wire of the winding extend parallel
30 to each other or are twisted in small bundles, which extend parallel to each other. These small bundles may for instance consist of Litz wires having twisted or braided wires, the winding wire comprising several of such Litz

wires which extend parallel to each other.

In such known windings, the heat conduction of the winding perpendicular to the direction of the winding is very
5 small compared to the heat-conduction of copper. Therefore the winding is often impregnated with special materials to increase the thermal conductivity, but even then the thermal conductivity in transversal direction of the winding is relatively small and the possible cooling of
10 the winding is limited.

By the zigzag pattern according to the invention, the heat can be transferred along the wires to the edge of the winding and so to the cooling medium instead of having to
15 jump through the insulation from one wire to the other and the heat may be dissipated laterally to a much greater extend than when the conductors are parallel.

DE-C-496.884 discloses a method for manufacturing a
20 winding wire wherein the conductors extend from on edge of the wire to the other. However this document does not disclose how such wire is used in a winding. Nothing is suggested that the edges of the wire are also the edges of the winding and are in thermal conductive contact with a
25 cooling medium. On the contrary, with the purpose of cooling, the winding wire may be made hollow, comprising thus a channel for cooling air.

According to the invention, the zigzag pattern may be
30 under angles between 5° and 45° and preferably between 10° and 30° with respect to the mean longitudinal direction of the winding.

More particularly, the winding wire may consist of a wire formed by a flat and wide packet of insulated conductors, each conductor extending in zigzag from one side of the packet to the other.

5

The cooling medium may be a fluid having access to the gaps and the whole housing may then form a fluid tight chamber for cooling fluid or the housing may be separated in two separated spaces by means of a tube surrounding a
10 rotor, the space on the outside of this tube forming an fluid tight chamber comprising the windings.

This chamber may be filled with the cooling fluid, for example cooling oil or the housing may be provided with at
15 least one inlet and at least one outlet for the cooling fluid, in fluid communication with the chamber, the cooling means comprising means for forcing cooling medium through the inlet inside the housing, along the windings and through the outlet outside the housing.

20

The invention will now be described by way of example and with reference to the accompanying drawings, in which:

Figure 1 represents an axial section of an electric
25 motor provided with a stator and windings, according to the invention;

Figure 2 is a top view of the stator with windings from the motor of figure 1;

Figure 3 is an end view of the stator with windings
30 of figure 2;

Figure 4 is a perspective view of the stator with windings of figures 2 and 3;

Figure 5 represents an axial section similar to the

one of figure 1, but relating to another embodiment of the motor;

Figure 6 represents one possible electrical connection of the stator windings in a three-phase motor, according to the invention;

Figure 7 represents a view similar to the one of figure 3, but showing the electrical connections to the windings;

Figure 8 represents a section along line VIII-VIII in figure 5, on a larger scale;

Figure 9 represents a section along line IX-IX in figure 8, on a still larger scale;

Figure 10 represents a section similar to the one of figure 9, but with respect to another form of embodiment;

Figure 11 represents a section similar to the one of figure 8, but with respect to another form of embodiment.

20 The electrical machine shown in figure 1 is an electric motor, comprising essentially a rotor 1, a stator 2 surrounding the rotor 1 and a housing 3 surrounding the stator 2.

25 The housing 3 is approximately cylindrical with closed ends and the rotor 1 contains a rotor body 4 mounted on a shaft 5 which is journaled in these closed ends by means of bearings 6.

30 The rotor 1 is surrounded by a tubular separation wall 7, separating the rotor 1 from the stator 2 and forming a fluid tight chamber 12 for the stator.

The stator 2 has a tubular core 8 and is provided with a number of stator windings 9, electrically insulated from each other and surrounding the wall of the core 8 and consequently traversed in their centre by core 8 and
5 extending in axial and radial direction with respect to the longitudinal axis of the core 8 which axis coincides with the rotation axis of the rotor 1.

As shown in detail in figures 2 to 4, these windings 9
10 have the shape of thin discs, having in the example given a constant thickness.

The discs fan out like the rays of a star, and are oblong in the direction of the axis of the rotor 1 with rounded
15 ends.

Each disc forming winding 9 is provided with an axial slot for the core 8. Part of each disc is situated in the air gap between the rotor 1 and the core 8, but inside the
20 stator chamber 12, and part in the air gap 13 between the core 8 and the housing 3, on the outer side of the core 8.

The windings 9 may be made from bundles of wires or strands surrounding the core 8 or from a single wire, for
25 instance a Litz wire.

The winding 9 may also consists of a wire 18 comprising a number of individually insulated conductors 19, but these conductors 19 are extending in zigzag so that each
30 conductor 19 regularly reaches the outer surface or edge of the winding 9. The conductors 19 may be single wires as shown in figures 8 and 9 or may be strands or bundles.

The zigzag pattern is under angles α between 5° and 45° , preferably between 10° and 30° with respect to the mean longitudinal direction of the winding 9 and the wire 18.

- 5 The conductors 19 may be included in a flat and wide packet with nearly rectangular section as represented in figures 8 and 10, each of the conductors 19 reaching from one side of the packet to the other side, e.g. in the form of a plait.

10

The packet of insulated conductors 19 may for instance be surrounded by an envelope 18A of electrical insulating material, as shown in the figures 2 and 3.

- 15 In fact the wire 18 may be considered as a flattened Litz wire.

- Tests have shown that the heat conductivity of the winding 9 with winding wire 18 according to the invention with
20 conductors 19 zigzagging from one edge of the winding to the other, is more than ten times that of a winding with parallel standard Litz wires.

- In another embodiment, the conductors 19 are not held
25 together by an envelope 19A but may be held together in the packet by forming a braid or plait, in which case the envelope may be omitted. This could still improve the heat dissipation. Figure 10 shows such embodiment.

- 30 The different layers of this wire or these wires or strands in a winding 9 may be held together by means of an insulating varnish.

In an extreme embodiment, the discs may be solid conductors, particularly copper rings.

5 The windings 9 may be held into place by means of supports 10. These supports may be insulating pieces fixed to the core 8. Only two such supports 10 are schematically shown in figure 3, but it is clear that such support 10 is present between each pair of adjacent disc forming windings 9.

10

It is important that also on the inside of the core 8 there is a gap 11 between two adjacent disc shaped windings 9, at least over an important radial distance, more particularly over at least 95%, and preferably over 15 the complete radial dimension of the discs as shown in the figures 2 to 4 and 7.

The stator chamber 12 and consequently also the spaces or gaps 11 between the disc-shaped windings 9 are filled with 20 a cooling medium.

This cooling medium is preferably a liquid such as transformer oil. This liquid is stationary.

25 In another embodiment, the cooling medium is circulating, and the housing 3 is provided with one or more inlets 14 and one or more outlets 15 on opposite sides, in fluid communication with the stator chamber 12, as shown in figure 5. Means such as a fan or pump (not shown in the 30 figures) are provided for forcing cooling liquid through the inlet, along the windings 9 and through the outlet. This cooling medium may be a gas such as air, forced over the windings 9, in which case the tubular wall 7 is not

necessary, and in the embodiment of figure 5, this wall 7 is absent.

5 In still another embodiment, the cooling medium is solid and for example formed by portions of the stator 2 as shown in figure 11.

10 The packet constituting the wire 18 extends from one portion of the stator 2 to another. The wire 18 can be considered being situated in a channel 20 formed in the stator 2, the edges of the wire 18 touching the walls of the channel 20.

15 There may also be a thin electrical insulation between the wall of the channel 20 and the winding 9, whereby the insulation is so thin that thermal conduction from the conductors 19 towards the walls of the channel 20, which are in heat conducting material of the stator 1, mostly iron, is not prevented.

20 Thermal paste may be used to improve the cooling of the winding 9 against the iron of the stator 2 or another cold wall.

25 In all described embodiments, the disc-like shape of the windings 9 positioned in a star-disposition has as an excellent cooling as a result. Especially on the ends of the windings, heat may be dissipated more efficiently than with a conventional design.

30 The conductors or wires forming several disc-shaped windings 9 may be electrically connected to each other as shown in figures 6 and 7. When the discs are formed by

windings, a same wire can form the windings and extend from one disc 9 to the other and form the windings for several discs 9.

- 5 Figure 6 shows the electrical connection of the windings in a three phase, two pole motor with Y-connection, R, S, T designating the phases and r, r*, s, s*, t, t* designating the normally used windings spread over six half-sectors.

10

As can be seen in figures 6 and 7, each of the six classical "windings" r, r*, s, s*, t and t* for each pole related to one phase is split into a number, in the given example four windings 9, electrically connected in series
15 with each other by conductors 16.

When a cooling medium is present, there is a long contact distance between the cooling medium and the windings 9 on both sides of the core 8 and also a contact of the cooling
20 medium with the inner side of the core 8.

Also on the inner side of the core 8, the sides of the windings 9 form cooling areas in contact with a liquid or gaseous, stationary or flowing cooling medium.

25

The splitting up of the classical windings r, r*, s, s*, t and t* in several windings 9 multiplies the contact surface with the cooling medium and improves considerably the cooling.

30

Claims.

- 1.- Electrical machine, for example a motor or a
5 generator, comprising a housing (3) and therein a stator
(2) comprising a tubular core (8) and windings (9)
surrounding the core wall, said stator windings (9)
extending axially and radially with respect to the axis of
the core (8); the machine comprises means for cooling the
10 windings (9), characterised in that as well on the inside
as on the outside of the core (8) the windings (9) are for
at least 95% spaced apart, forming a gaps (11) between
them, the cooling means comprising a cooling medium in
these gaps (11).
- 15 2.- Electrical machine according to claim 1, characterised
in that the windings (9) of the stator (2) are completely
spaced apart.
- 20 3.- Electrical machine according to claim 1 or 2,
characterised in that the windings (9) of the stator (2)
have the shape of thin discs.
- 4.- Electrical machine according to claim 3, characterised
25 in that the discs have a constant thickness.
- 5.- Electrical machine according to claim 3 or 4,
characterised in that the discs are oblong, and at their
ends they are rounded.
- 30 6.- Electrical machine according to either one of claims
1 to 5, characterised in that the stator (2) comprises
supports (10) for the holding into place the windings (9).

7.- Electrical machine according to any one of the preceding claims, characterised in that the windings (9) are segments of the windings normally provided for each pole relating to one phase.

8.- Electrical machine according to either one of the preceding claims, characterised in that the windings (9) comprise a wire (18) consisting of individually insulated conductors (19), these conductors being wires or strands.

9.- Electrical machine according to claim 8, characterised in that insulated conductors (19) extend in a zigzag pattern between the edges of the winding (9) said edges being in thermal conductive contact with the cooling medium.

10.- Electrical machine according to claim 9, characterised in that the zigzag pattern is under angles (α) between 5° and 45° , and preferably between 10° and 30° , with respect to the mean longitudinal direction of the winding (5).

11.- Electrical machine according to claim 9 or 10, characterised in that the windings (9) consist of a wire (18) formed by a flat and wide packet of insulated conductors (19), each conductor (19) extending in zigzag from one side of the packet to the other.

12.- Electrical machine according to claim 9 or 10, characterised in that the windings (9) consist of a wire (18) in the form of a packet of insulated conductors (19) extending in zigzag in the form of a plait or braid.

13.- Electrical machine according to either one of the preceding claims, characterised in that the complete housing (3) is fluid tight and form a tight chamber (12)

5

14.- Electrical machine according to either one of claims 1 to 12, characterised in that the housing (3) is separated in two separated spaces by means of a tube (7) surrounding a rotor, the space on the outside of this tube (7) forming an fluid tight chamber (12) comprising the windings (9).

10

15.- Electrical machine according to claim 13 or 14, characterised in that the cooling medium is a cooling fluid and the chamber (12) is filled with such cooling fluid, for example cooling oil.

15

16.- Electrical machine according to claim 13 or 14, characterised in that the cooling medium is a cooling fluid and the housing (3) is provided with at least one inlet (14) and at least one outlet (15) for the cooling fluid, in fluid communication with the chamber (12), the cooling means comprising means for forcing cooling medium through the inlet (14) inside the housing (3), along the windings (9) and through the outlet (15) outside the housing (3).

20

25

17.- Electrical machine according to claim 15 or 16, characterised in that it is an air-gap wound motor and the cooling medium in the gaps (11) between the windings (9) is gaseous or liquid.

30

18.- Electrical machine according to either one of claims

1 to 14, characterised in that the cooling medium is a solid heat conducting material and the windings (9) are in heat conductive connection with this solid heat conducting material, for instance the iron of a stator (2).

1/3

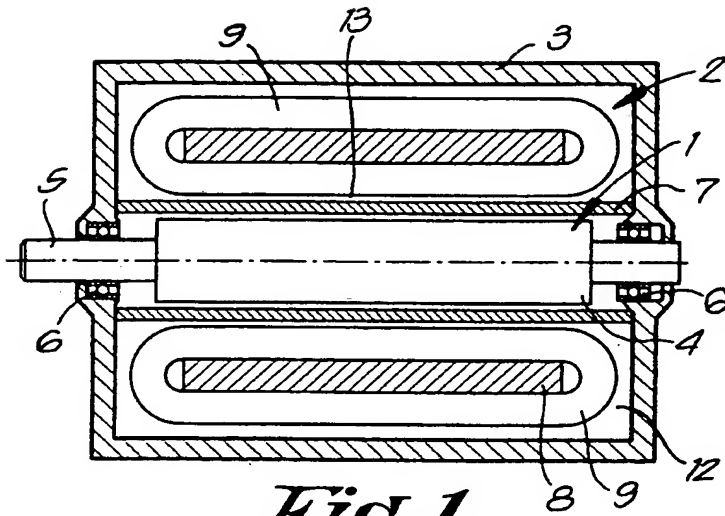


Fig. 1

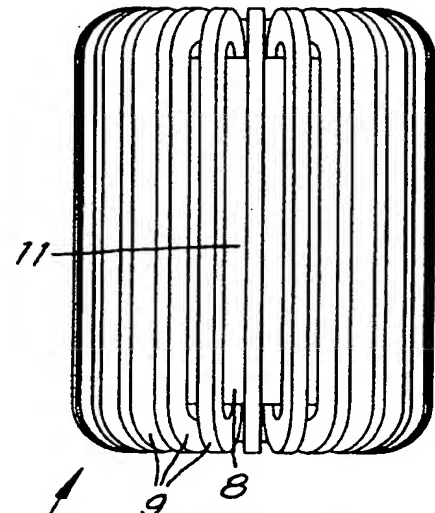


Fig. 2

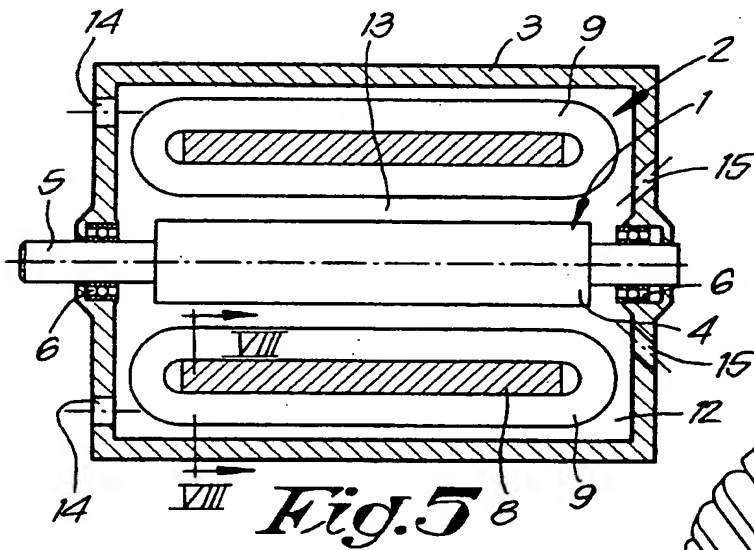


Fig. 5

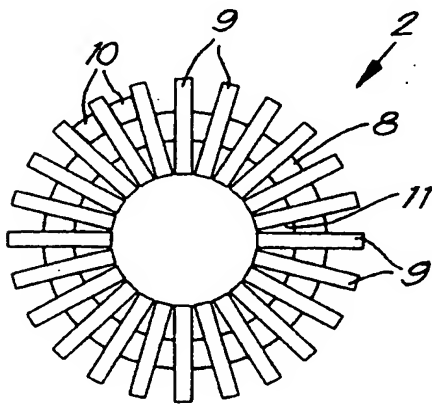


Fig. 3

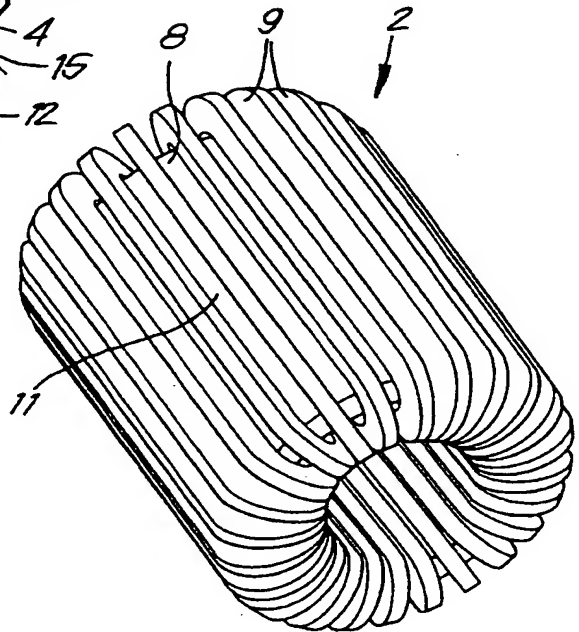
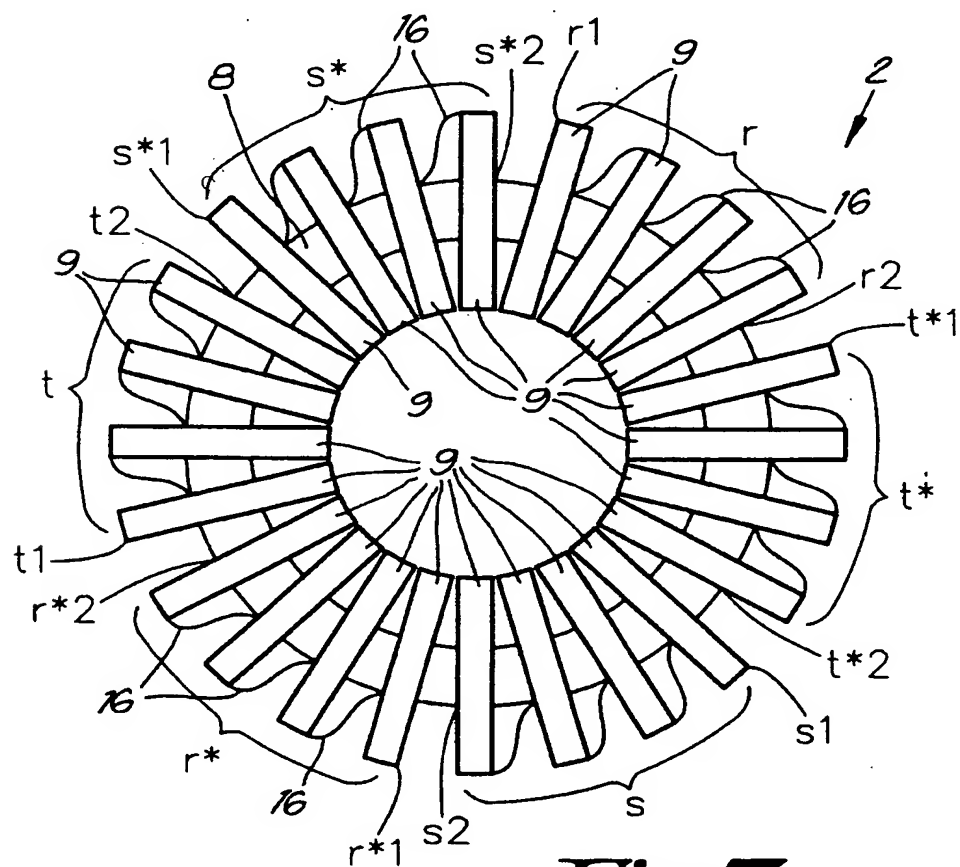
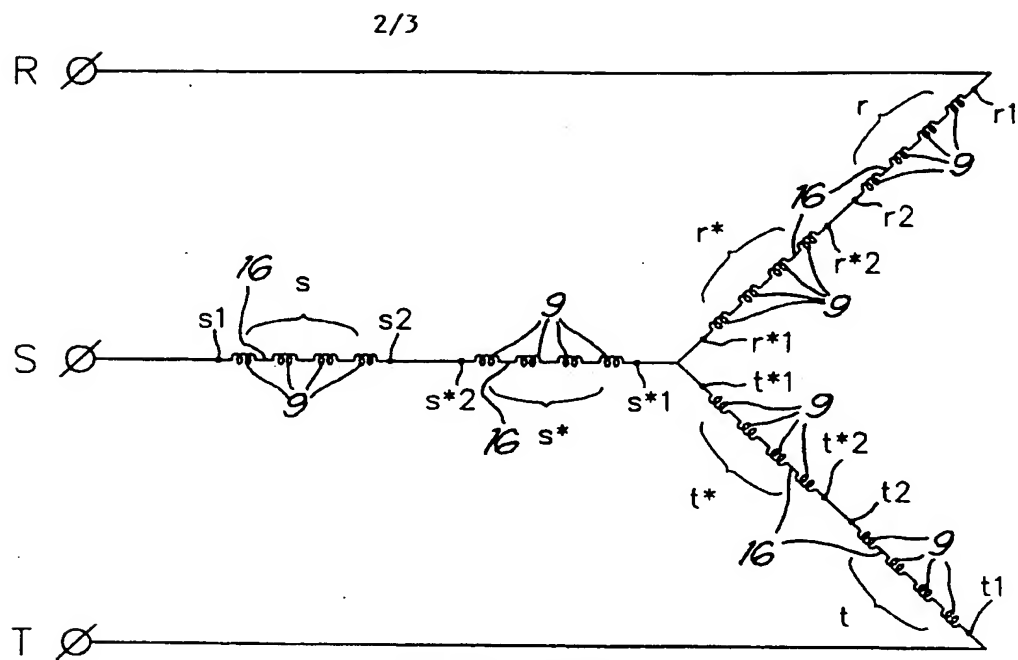


Fig. 4



3/3

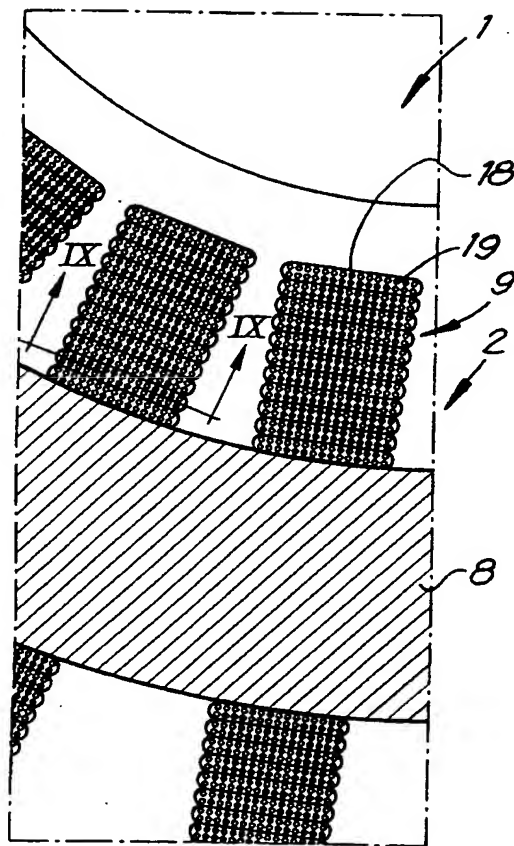


Fig. 8

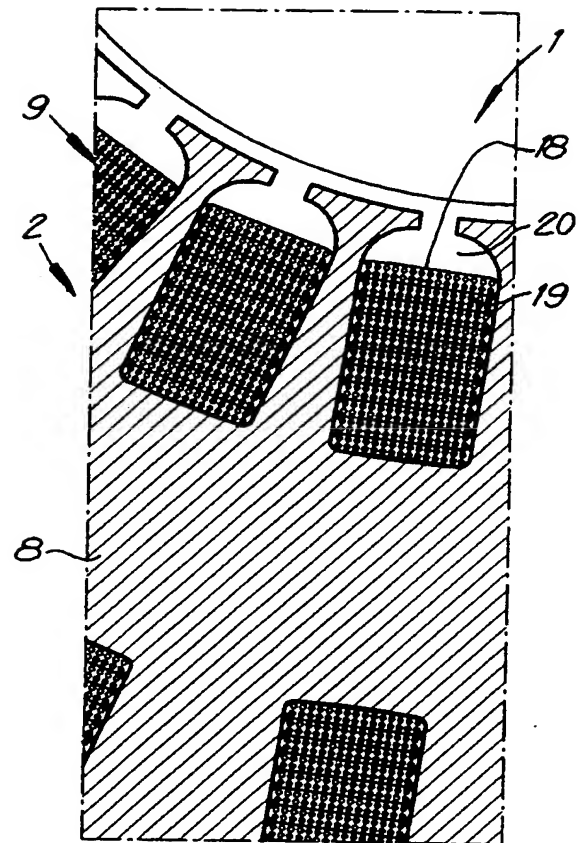


Fig. 11

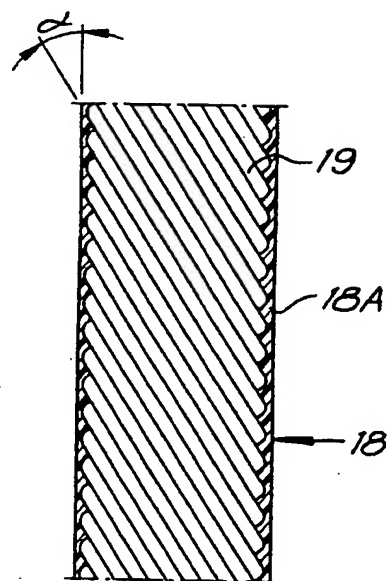


Fig. 9



Fig. 10

REST AVAILABLE COPY

INTERNATIONAL SEARCH REPORT

International Application No
PCT/BE 00/00136

A. CLASSIFICATION OF SUBJECT MATTER IPC 7 H02K3/04 H02K9/197 H02K9/19		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC 7 H02K H01F		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal, WPI Data, PAJ		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 103 197 A (IKEGAMI KEISUKE ET AL) 25 July 1978 (1978-07-25) -----	
A	US 5 304 883 A (DENK JOSEPH) 19 April 1994 (1994-04-19) -----	
A	US 4 563 606 A (FUKASAWA IKO ET AL) 7 January 1986 (1986-01-07) -----	
A	WO 94 22204 A (SKYBYK DYMTRIO) 29 September 1994 (1994-09-29) -----	
A	DE 496 884 C (SIEMENS-SCHUCKERTWERKE AG) 10 April 1930 (1930-04-10) -----	
<input type="checkbox"/> Further documents are listed in the continuation of box C. <input checked="" type="checkbox"/> Patent family members are listed in annex.		
* Special categories of cited documents : <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>*A* document defining the general state of the art which is not considered to be of particular relevance</p> <p>*E* earlier document but published on or after the international filing date</p> <p>*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>*O* document referring to an oral disclosure, use, exhibition or other means</p> <p>*P* document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>*Z* document member of the same patent family</p> </div> </div>		
Date of the actual completion of the international search <div style="text-align: center; font-weight: bold;">19 February 2001</div>		Date of mailing of the international search report <div style="text-align: center; font-weight: bold;">26/02/2001</div>
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016		Authorized officer <div style="text-align: center; font-weight: bold;">Ramos, H</div>

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/BE 00/00136

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 4103197	A	25-07-1978	AT 364027 B AT 206776 A CA 1052433 A DE 2611506 A FR 2305001 A GB 1534724 A NL 7602943 A	25-09-1981 15-02-1981 10-04-1979 07-10-1976 15-10-1976 06-12-1978 21-09-1976
US 5304883	A	19-04-1994	NONE	
US 4563606	A	07-01-1986	JP 1811083 C JP 5014506 B JP 59014336 A	27-12-1993 25-02-1993 25-01-1984
WO 9422204	A	29-09-1994	US 5334899 A	02-08-1994
DE 496884	C		NONE	